Assessmenttool for assessing theimpact of Ship/Boat Wake Waves onthe banks and protection measures for Inland National Waterways

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Abstract

It is well known that vessels in any waterway generate waves which in turn can sometimes have significant adverse effects on the river banks. In this proposal, it is proposed to develop a numerical model to arrive at the speed of the moving vessels to protect the banks of the inland national waterways. This is of immediate concern due to the recent government plan to extend our national waterways in a phased manner, as water transport is safe, cheap and has a lower carbon footprint. The need for this study is highlighted in this proposal with evidence from google images. The proposed study will ascertain the impact of vessel generated wake waves on the protected or unprotected banks of the waterways which is the need of the hour. In order to validate the developed numerical model for the moving vessels in a channel, it is proposed to carry out the field investigations(i) at the inner harbour area of Cochin port where the channels are narrower, and (ii) in 2 sites along the proposed National Waterways. Further, the use of existing empirical models from river and coastal engineering will be investigated for the design of bank protection.

Introduction

Navigable waterways, a fuel-efficient, environment-friendly, and cost effective mode of transport, have a huge potential to supplement the over-burdened rail and traffic congested roads. India has about 14,500 km of navigable waterways, comprising of rivers, canals, backwaters, creeks, etc. Despite our waterways being long, only about 55 million tons of cargo are transported annually through Inland Water Transport (IWT). The Ganga-Bhagirathi-Hooghly between Allahabad-Haldia (1620 km) in UP, Bihar, Jharkhand and West Bengal; the Sadiya-Dhubri stretch of river Brahmaputra (891 km) in Assam; and the Kollam-Kottapuram stretch of West Coast Canal along with Champakara and Udyogmandal Canals (205 km) in Kerala have been declared as national Waterways, asshown in Fig.1., which are being developed for navigation by the Indian Waterways Authority of India (IWAI).

The government of India, GOI, hasproposed to develop the identified five different national waterways on a large scale.This will no doubt lead to the economy growing exponentially while also serving as a sustainable mode of transportation with a significantly lower carbon footprint as compared to the conventional mode of road transport. However, ship generated waves have an impact on the stability of revetments caused by the erosion of banks that could be densely populated along certain stretches. A means of prescribing safety measures to mitigate this impact is absolutely essential.Hence, it is of immediate interest to develop a tool to analyse the impact of ship generated waves using field measurements and develop a well calibrated numerical model for the Indian Inland Waterways. Once the model is validated, it could be used to monitor any waterway with a high degree of confidence.

The ship/vessel generated wake waves can have a significant hydrodynamic impact on berthed vessels, wharf structures, and banks or shorelines. These can include serious economic consequences (e.g. the induced motion of berthed vessels can lead to loading/un-loading downtime), environmental consequences (e.g. bank or shore erosion) and safety issues (e.g. large, freak wave at beaches). A significant effort has been made by scientists to better understand the process of boat wake induced erosion in different parts of the world such as the California Delta (Bauer et al., 2002), Marlborough Sounds in New Zealand (Parnell, McDonald, & Burke, 2007), the Kenai River in Alaska (Dorava& Moore, 1997) and the Illinois and Mississippi River systems (Bhowmik, 1982). Erosion is a major concern for reasons relating to aquatic habitat, water quality, and loss of property as well as disruption of natural sedimentation processes in rivers and lakes.

Waves generated from vesselwakes differ from waves generated by wind. Boat waves are highly localized and dissipate in a matter of minutes after the passage of the boat, while, wind waves are 'spatially homogenous' and can last over tens of minutes to hours or even longer (Sheremet, Gravois, & Tian, 2012). The energy of a wind wave is determined by the force generated by the wind. As the wind pushes over the water, the force causes displacement on the water surface, thus forming a wave. These waves are created continually as long as the wind blows, and when superimposed across hours, they will have a huge amount of energy exerted on the banks. The energy of a boat wave is contained within a wake packet that usually consists of a few dozen waves that get smaller and smaller through time. The impact of boat-wake waves on bank erosion is determined by a number of factors, including displacement of the vessel, the length of the vessel in contact with the water, shape of the hull, and speed. How much energy is transferred to the shore from a boat wake will depend on the boat's proximity to the shore (Baldwin, 2008) and its direction of travel relative to the bank. Depending on the environment, even small boats can have a significant effect on bank erosion if the bank materials lack strength and structural integrity (Parnell, Kolofoed-Hansesn, 2001). In an attempt to quantify the relationship between bank erosion and boat wakes, Bauer et al., (2002) developed an analytical method in a well-instrumented experiment on a levee bank on the Sacramento-San Joaquin River Delta.

Over the past 20-30 years, a large number of studies have been conducted on the impact of recreational and commercial boating traffic on bank erosion along rivers, lakes, and large embankments. There is as yet no consensus regarding the precise amount of erosion that can be caused by boats relative to natural processes involving currents, wind waves, and tidal fluctuations, but it is increasingly clear that boats do indeed play a role in acceleration of erosion rates. It was reported that in most cases, rivers and canals are meandering and significant widening of the waterways is occurring as a result of erosion.

For example, the lower Gordon River in Tasmania is a river that is being severely impacted by boat wake erosion and has been studied for quite some time (e.g., Bradbury, Cullen, Dixon, & Pemberton, 1995 and Bradbury, 2005). The current regulations permit a maximum wave height of only 0.075 m (i.e., 3 inches), which is extraordinarily small for any vessel passage. However, monitoring and experimental testing has demonstrated that this regulation is not very effective against erosion. This is due to recreational traffic not being subject to the regulation even though there is a disproportionally large impact. A report published by Bradbury (2005) uses geomorphic evidence to create guidelines and recommendations for cruise vessels to reduce the impacts of vessel wakes on the river. This proposal includes specific licensing for cruise vessels and revision of current speed limits to a 9 km/h maximum speed limit.

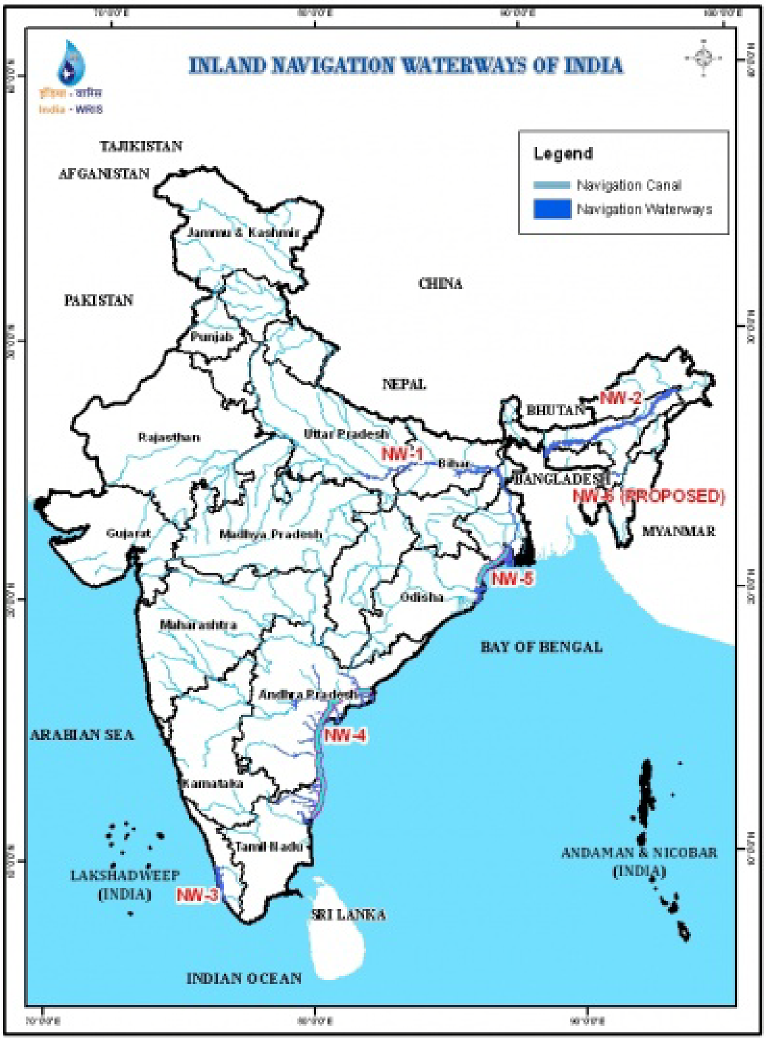

Fig.1. Proposed development of the Five Inland Navigation waterways.

Similar such studies have been conducted in the Kenai River, Alaska which is economicallyimportant for the salmon industry as it generates $78 million annually in direct benefits. The river is under a strict watch by resource management agencies due to a rising concern that increased sedimentation and loss of streamside habitat is occurring as a result of accelerated erosion from boat wakes.The peak boating period coincides closely with the annual return of salmon and also with measured peaks of bank erosion (Dorava and Moore, 1997). More than 20,100 boats were observed at a specific site along the river and a loss of nearly 1.14 m of bank width was observed during the observation period. Previous to the study, large scoured embayments were documented, indicating that boat wake erosion has most likely been a problem in the area for a long period of time (Dorava and Moore, 1997).However, it was noted that the amount of boat wake-induced erosion occurring on the river banks is dependent on water flow also. If the peak boating period occurs during low flows, the energy from boat wakes will be expended across the cobble bars at the margins of the river, thereby protecting the banks from significant erosion. However, if the peak boating period occurs during somewhat higher flows, the energy from boat wakes will be transferred directly to the banks above the cobble bars. Thus, it appears that the erosive impact of boat traffic is partly mitigated by low flow conditions during the year (Maynord et al., 2010).

Some attempts have been made to reduce erosion along the Sacramento River system include the additionof spurs which are referred to as groynes for protecting a coast in coastal engineering practice. Groynes are rigid structures that extent from the shore with a purpose of interrupting water flow. They are widely used on ocean beaches, and have been found to significantly reduce rates of erosion and limit the movement of sediment (Ercan and Younis, 2009). Groynes are used in both coastaland river systems, but their design is distinct for each location.Rivergroynes are commonly used to prevent bridge scouring. However,groynes have a large disadvantage as they cause significant problems downstream from their location. An investigation into the effectiveness of groynes on the Sacramento River was conducted by Ercan and Younis (2009), and they concluded that without groynes, themaximum erosion rate was estimated to be 5.6 m per year,while the same was reduced to 4.7 m per year with the installation of four groynes.

It is important to appreciate that even if boat traffic were to be eliminated completely from a river system, erosion by natural factors could still prevail (Maynord et al., 2010). Thus, it is critical to understand the natural dynamics of rivers as the natural backdrop against whichthe impact of boating traffic can be assessed. Changes in channel position are inevitable alongwith recurring flooding events, so river managers have to plan accordingly to allow the riversufficient space to meander naturally instead of creating bank stabilization techniques which tend to restrict the course of the river (Baldwin, 2008). In this context, the appropriate question is not whether vessel wakes cause erosion, because they most certainly do to some extent. Rather the more significant question deals with the degree to which vessel-wake induced erosion might be accelerating or substantively modifying the natural tendency for rivers to erode and rebuild their banks as part of the natural process.

Justification for the present study

However, to the best of authors' knowledge, there has been no study of the Indian National Waterways and the effect of vessel wakes, if any, on the banks. Whereas, some may argue that we currently do not have high speed or large vesseltraffic in our waterways that could generate significant wake induced sediment transport.However, in order to substantiateeither view, we lack historical records of bank and shoreline positions. Further, it should be noted thatcurrentlythe movement of cargo in National waterways 1, 2, and 3 are 3, 2 and 1 million tonnes respectively (as per IWAI records).Since the government plans to increase the cargo movement and extend the national waterways, it then becomes of immediate interest to develop an assessment tool. Significant vessel wakes can be observed in the satellite images of the HooghlyRiver in Fig.2, and in the Kollam- Kottapuramnational waterways, Fig.3. It is clearly evident that the wake waves do reach the bank causing some sediment movement, and more interestingly one can see a transition groin field constructed to protect the paddy field. Thus, providing evidence for the need of the proposed study, namely

(a) the need to evolve a system to obtain the optimal speed of the vessels moving in our river streams thereby reducing possible erosion
(b) guidelines for the design of bank protection that is site specific.

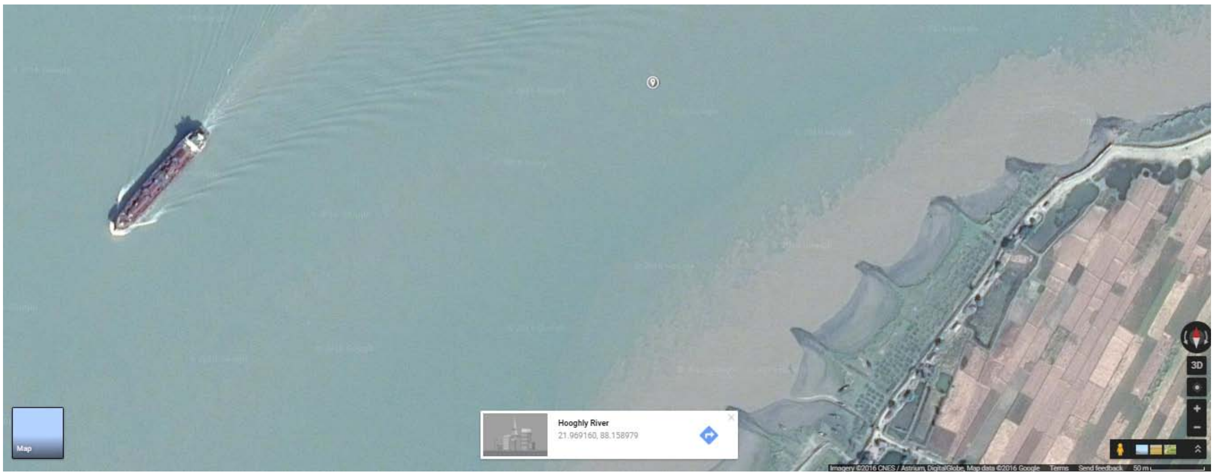

Fig.2. A container ship passing in a Hooghly river, the wake waves can be clearly seen and old groin/spur near the bank that protects a paddy field from erosion (source: Google maps).

Fig.3. The impact of boat generated wake near the side bank in a narrow channel of Kollam – Kottapuram National Waterways (source: Google maps)

Project Proposal

Thus, it is proposed to develop an assessment tool capable of prescribing upper bounds on the speed of the vessels moving in our national waterways with the goal of reducing possible erosion. The tool will also provide valuable inputs for the design of bank protection systems. As discussed previously, the assessment would be site specific in natureas it depends upon the bathymetry, strength of the materials on the bank, width and depth of the bank as well as the characteristics of the moving ship/boat such as draft, hull forms, speed, etc. Hence, one way to overcome this variability would be to develop a numerical model that could cater to these specific needs.

In order to develop a well calibrated numerical model as well as empirical models, one also needs to carry out field measurements in our National Waterways.In the present project the numerical model based on Boussinesqmodel that incorporates a moving vessel will be developed. This model will be validated with the field measurements to be carried out (i) at the inner harbour area of Cochin port where the channels are narrower, and (ii) in 2 sites along the proposed National Waterways. Further, the use of empirical model that was developed based on field measurements and laboratory scale tests for ship wave height predictions from Sorensen (1973) will be investigated for our inland national waterways.Development of the numerical model based on Boussinesq equations can also be used to assess the movement of ships near ports and harboursthereby aiding in their restoration work. Further, the developed model would be useful in carrying out any basic research on the wake wave pattern and group effects of moving ships in shallow water.

Despite the problem central to this study being an important one that is vital for the development of the naturally available large network of waterways in India, not much work (in fact no published work) has even been initiated.

Methodology

An overview of the assessment methodology proposed for our inland waterways is shown in Fig.4.

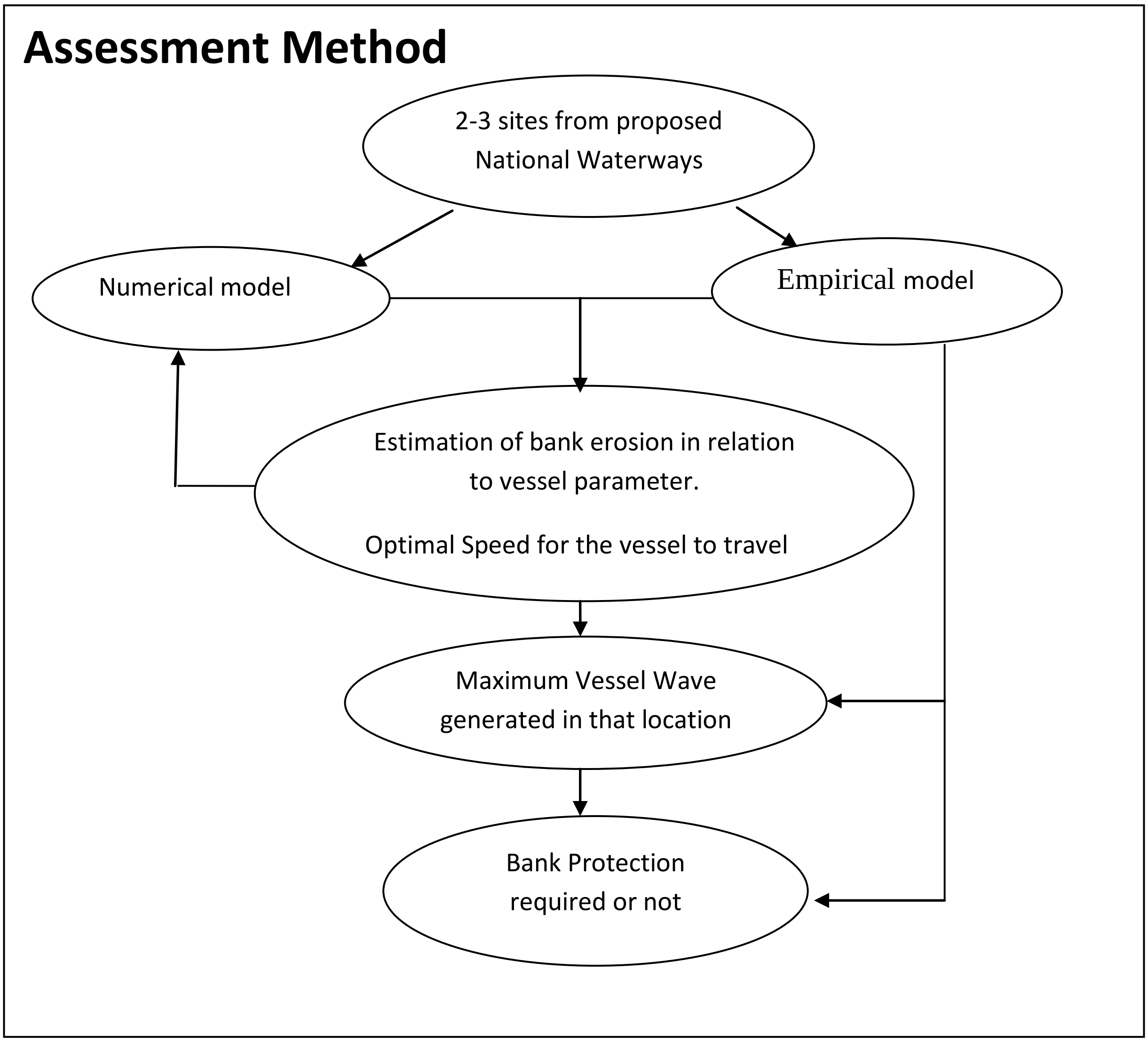

Fig.4. Proposed Assessment methodology

The details about the proposed numerical model with the governing equations and boundary condition to represent the physical problem are shown in Fig.5.

Governing Equations

Continuity Equation

$$\eta_t + \nabla.\left\{(h+\eta)\left[u_\alpha + \left(z_\alpha + \frac{1}{2}(h-\eta)\right)\nabla(\nabla.(hu_\alpha)) + \left(\frac{1}{2}z_\alpha^2 - \frac{1}{6}(h^2 - h\eta + \eta^2)\right)\nabla(\nabla.u_\alpha)\right]\right\} = 0$$

Momentum Equation

$$\begin{aligned} u_{\alpha t} + (u_\alpha.\nabla)u_\alpha + g\nabla\eta + z_\alpha\left\{\frac{1}{2}z_\alpha\nabla(\nabla.u_{\alpha t}) + \nabla(\nabla.(hu_{\alpha t}))\right\} \\ + \nabla\left\{\frac{1}{2}(z_\alpha^2 - \eta_\alpha^2)(u_\alpha.\nabla)(\nabla.u_\alpha) + \frac{1}{2}[\nabla.(hu_\alpha) + \eta\nabla.u_\alpha]^2\right\} \\ + \nabla\left\{(z_\alpha - \eta)(u_\alpha.\nabla)(\nabla.(hu_\alpha)) - \eta\left[\frac{1}{2}\eta\nabla.(u_{\alpha t}) + \nabla.(hu_{\alpha t})\right]\right\} = -\sum_{j=1}^{N}\frac{\nabla p_j}{\rho} \end{aligned}$$

Bed Sediment Transport

$$q_b = \alpha_b \rho_s u d\left(\frac{d_{50}}{d}\right)^{1.2} m_f^{1.5}$$

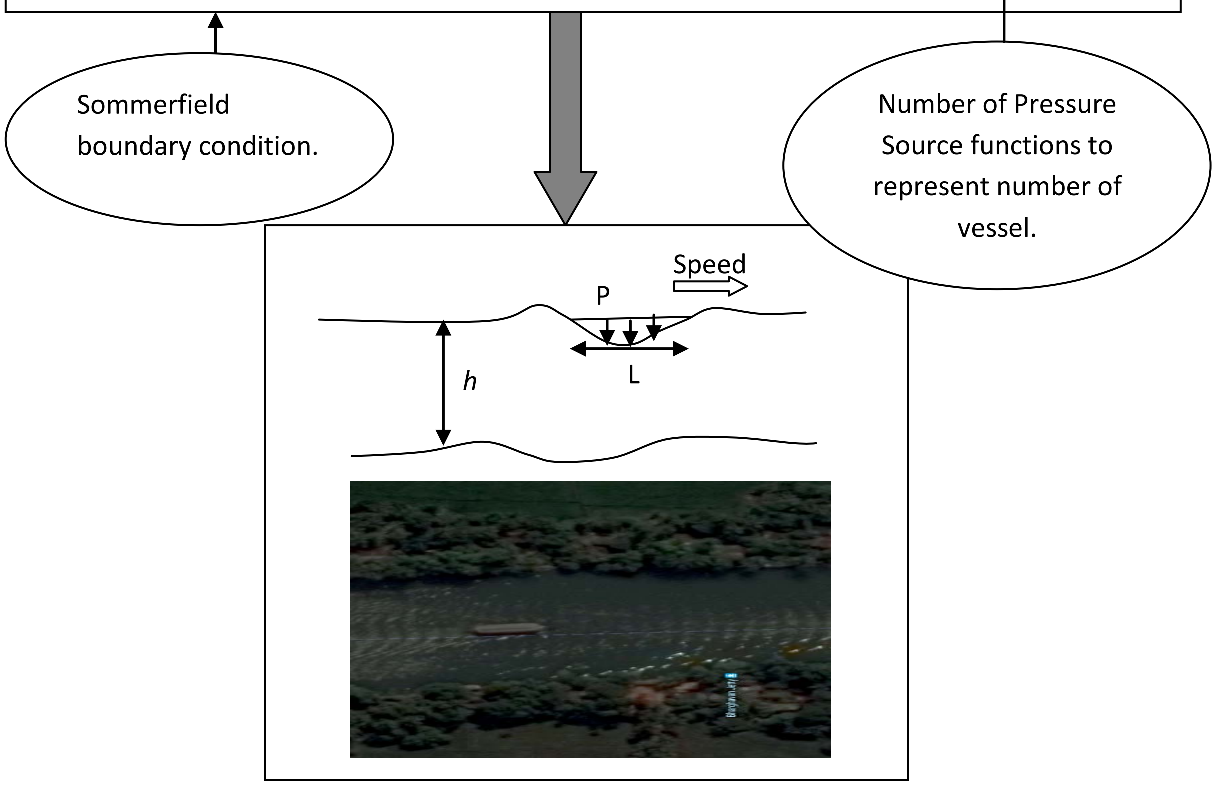

Fig. 5.Governing Equations and boundary conditions in shallow water to solve the physical problem at the bottom.

Usefulness of the study to the sector

- Arriving at optimal traffic conditions in terms of vessels speeds and sizes for a given waterway.
- Designing cost effective bank protection due to design / envisaged traffic conditions.
- Strategize future development possibilities for coastal shipping / inland waterways.
- Address the social issues on the coastal areas / river banks in a scientific manner.
- A tool for estimating river bank erosion due to waves and vessel movement.

Earlier studies carried out in the subject

- Bank protection work at Kochi Port channel mouth.
- Hydrodynamics and Siltation studies in the Hooghly River.

Project Milestone

Details	1st Year	2nd Year	3rd Year
Development of the numerical model based on Boussinessq equation.			
Procurement of Equipment for field measurements			
Field measurements (i) at the inner harbour area of Cochin port where the channels are narrower, and (ii) in 2 sites along the proposed National Waterways"(for a month) to validate the numerical model.			
Validation of the existing empirical model for the Indian condition.			
Publications of results in journal and conferences			

Financial Requirements

PARTICULARS	1st year	2nd year	3rd year	Total	Justification of the cost
Man power					
Project Officer x 2nos	840,000.00	924,000.00	10,16,400.00	27,80,400.00	Numerical model development.
Project Associate x 1nos	300,000.00	330,000.00	363,000.00	993,000.00	Man power for field studies
Project Attendant x 1nos	216,000.00	237,600.00	261,360.00	714,960.00	
Equipment					
River Ray ADCP: velocity measurement	20,00,000.00			20,00,000.00	To measure velocity and discharge.
Wave Probe: wave height measurement	10,00,000.00			10,00,000.00	Pressure sensor to measure height.
Turbidity meter					Equipment already included under NTCPWC
Float measurement: alongshore transport					Equipment already included under NTCPWC
Bed profile of river					Equipment already included under NTCPWC
Boat hire charges	4,50,000.00	4,50,000.00	4,50,000.00	13,50,000.00	For field experiments
Consumables	1,00,000.00	1,00,000.00	1,00,000.00	3,00,000.00	
Contingency	3,00,000.00	3,00,000.00	3,00,000.00	9,00,000.00	Including expenses for field measurements
Air travel+ Site visit	4,50,000.00	4,65,000.00	4,81,500.00	13,96,500.00	Travel to the site –1month.
				11,434,860.00	
Subtotal (A)					
Service tax (B)				17,15,229.00	(15% of A)
IIT Overheads (C)				26,30,018.00	(20% of A+B)
Grand Total (A+B+C)				157,80,107.00	

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